Bioaccumulation Factors for Selenium in Lake Koocanusa: A Primer

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SeTSC

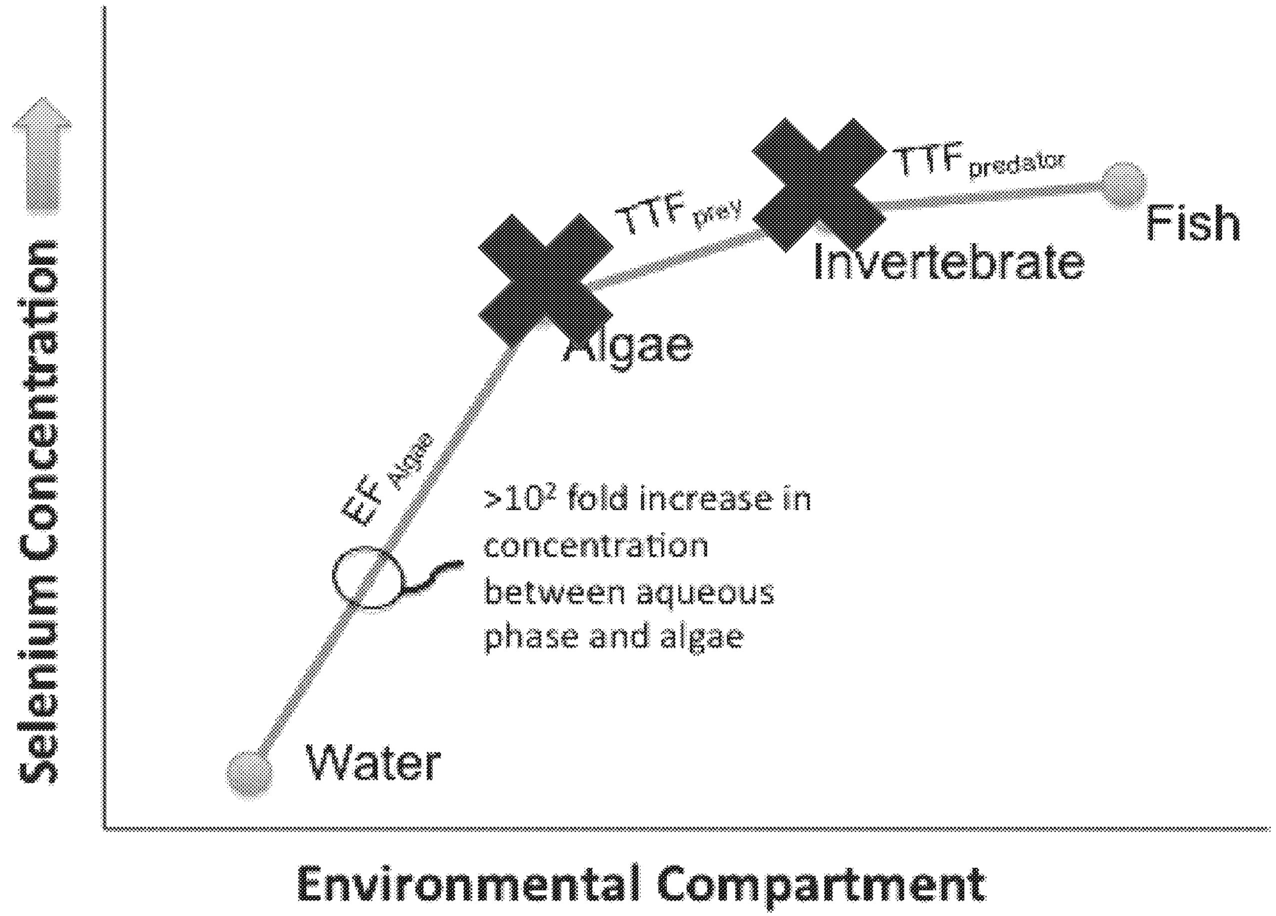
Issues to Discuss

- Background
  - What is a BAF?
  - Considerations for use of the BAF approach
- Use of BAFs in Lake K SSC process.
- Examples with "available" Lake K data

What is a Bioaccumulation Factor (BAF)?

- Empirical Modeling Approach (vs the Mechanistic modeling approach)
- establishes a relationship between concentrations of selenium in fish tissue and ambient water
- measuring selenium concentrations in both media
- calculating the ratio of the two concentrations
- ratio (BAF) can then be used to estimate the target concentration of selenium in the water column as related to the adopted fish tissue element

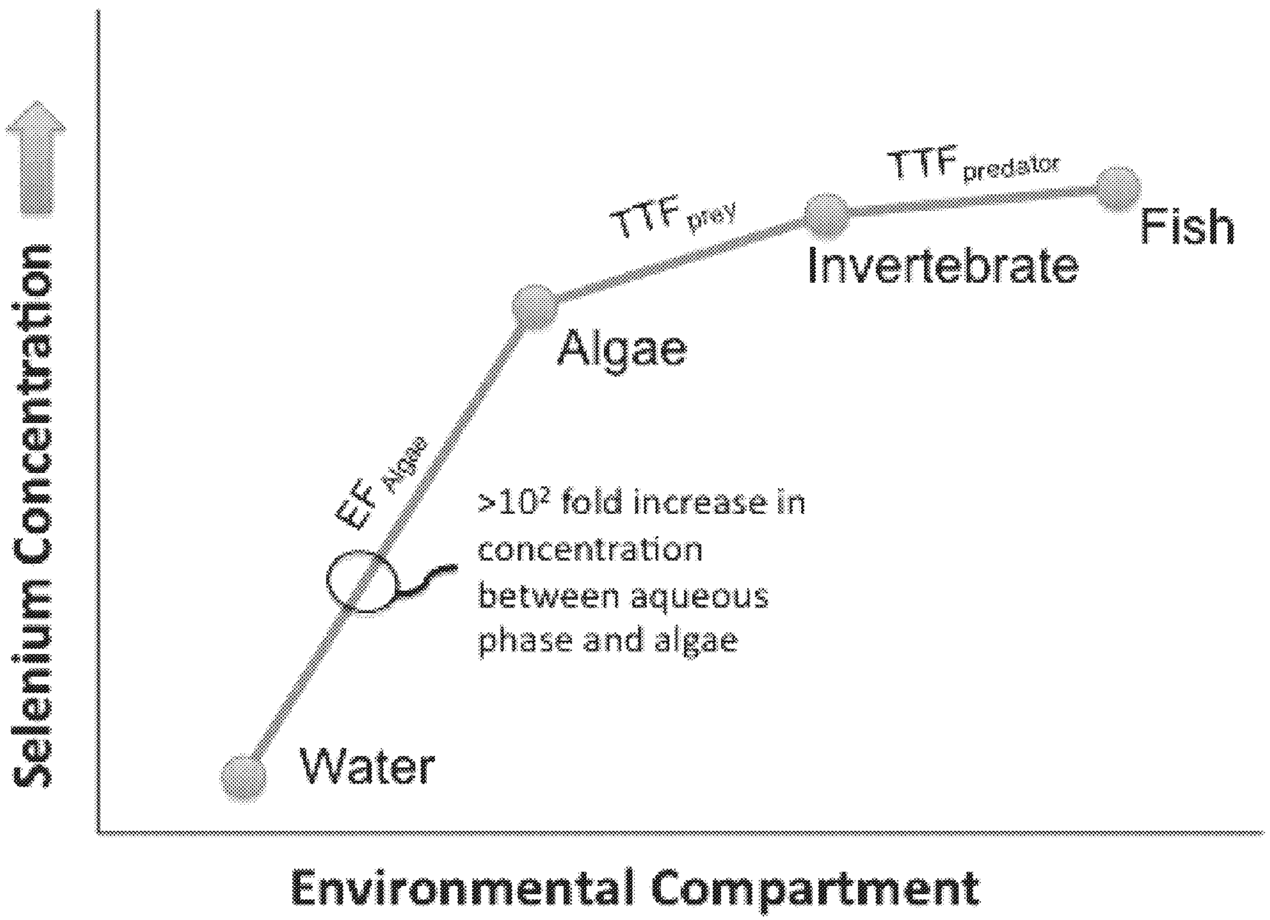
Bioaccumulation Factor Approach



$$BAF = \frac{C_{tissue}}{C_{water}}$$

$$C_{water}\ (SSC) = \frac{C_{egg\text{-}ovary\ criterion}}{BAF}$$

Mechanistic Model



$$C_{water} \text{ (SSC)} = \frac{C_{egg\text{-}ovary}}{TTF^{composite} \times EF \times CF}$$

Considerations for the Use of the BAF Approach

- BAFs are used to relate chemical concentrations in aquatic organisms to concentrations in the ambient media of aquatic ecosystems where
  - both the organism and its food are exposed, and ☑
  - the ratio does not change substantially over time ?

- BAFs are appropriate only for site-specific applications where
  - sufficient measurements have been taken from the site of interest, and ☑
  - there is little or no extrapolation of BAF values across differing exposure conditions and species ☑

- Lake Koocanusa Database is spatially and temporally “rich” (comparatively) in both fish and water measurements

Comparison of Decisions Needed for Modeling

Mechanistic Model

1. selecting a target fish species for the waterbody,
2. determining the primary food source for the target species,
3. determining the appropriate *TTF* values,
4. determining the appropriate *EF* value, and
5. determining the appropriate *CF* value.

Bioaccumulation Factor

1. selecting target fish species for the waterbody, and
2. determining the appropriate [selenium] in water

BAF Uncertainties & Their Management

- Inaccurate water concentration values (SSCs) result when BAFs are derived from:
  - water and fish tissue concentration measurements that are obtained from sources that do not closely represent site characteristics – **not applicable**
  - field data collected from large-scale sites that encompass multiple water bodies or ecosystems – **can be managed based on fish species selection and pairing appropriate water collection sites**

- Most of this uncertainty results from differences in the bioavailability of selenium between the study sites where measurements are made to derive the BAF –
  - necessitates consideration of spatial variability in [selenium]
  - selenium speciation (particularly in northern part of the lake) still uncertain

- Managing uncertainty between the values derived by the BAF approach and the mechanistic model.
  - Managed by using similar modeling assumptions as those selected for the mechanistic model (1^{o} model), to the extent practicable (based on the limits of the data).

Use of BAFs to Derive SSC for Lake Koocanusa

- Considerations
  - Need to consider the four “levels of protection” options developed by the SeTSC.
  - Need to consider the spatial and temporal limitations of the available data and the biology of the fish species selected for use in BAF modeling.
  - BAF modeling assumptions need to be as consistent as possible with the model assumptions chosen for the mechanistic model since this results of this modeling approach is considered secondary to the BAF, and will be used a check of the mechanistic model to “ground truth” those results.

Use of BAFs to Derive SSC for Lake Koocanusa Levels of Protection

- Alternative 1: the model-derived water-column criteria will provide a level of protection expected to ensure that the maximum value of any individual of any species in the lake will not exceed the BC egg-ovary criterion of 11.0 mg Se/kg.

- Alternative 2: the model-derived water-column criteria will provide a level of protection ensuring that the population value for any species in the lake will not exceed the BC egg-ovary criterion of 11.0 mg Se/kg

Use of BAFs to Derive SSC for Lake Koocanusa Levels of Protection

- Alternative 3: the model-derived water-column criteria will provide a level of protection expected to ensure that the maximum value of any individual of any species in the lake will not exceed the USEPA egg-ovary criterion of 15.1 mg Se/kg.

- Alternative 4: the model-derived water-column criteria will provide a level of protection expected to ensure that the population value of any species in the lake does not exceeds the USEPA egg-ovary criterion of 15.1 mg Se/kg.

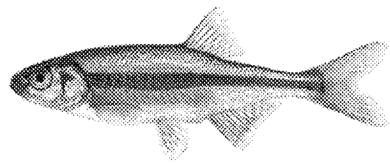
Considerations for Levels of Protection

- Alternatives 1 and 3 call for every individual member of the species to be protected from harm (EO < 11.2 or 15.1 mg/kg respectively)
  - These levels of protection alternatives require more conservative assumptions for model parameters (e.g., EF, TTF, BAF) used in both approaches to insure the appropriate protection is conveyed to the aquatic ecosystem.
- Alternatives 2 and 4 call for the species (as a whole) to be protected from harm (EO < 11.2 or 15.1 mg/kg respectively)
  - These levels of protection alternatives require less conservative assumptions (e.g., central tendency) for model parameters used in both approaches to insure appropriate protection is conveyed to the aquatic ecosystem
- There is uncertainty inherent in both approaches
  - SeTSC decision-making on modeling assumptions for both approaches needs to be documented and transparent to provide a defensible record for regulatory process.
  - Uncertainty analysis (final report) needs to be transparent for both approaches.

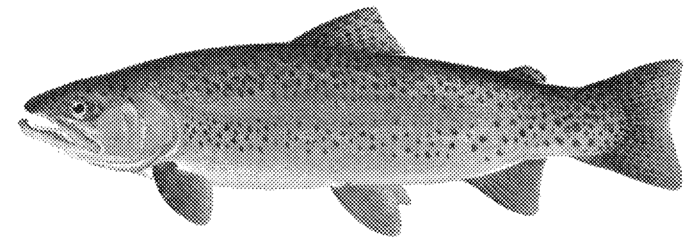
Fish Species Selection for BAF Model

- Selection of the fish species in the aquatic system with the greatest selenium sensitivity and bioaccumulation potential is recommended.
    - Sensitivity – white sturgeon downstream; salmonids (RBT, K, WSCT in lake)
    - Bioaccumulation potential – cyprinids (minnows) – RSS, PC, NPM; suckers (LSS, LNS); salmonids (MW) in lake
- In aquatic systems with resident fish species of unknown selenium sensitivity and bioaccumulation potential, other factors such as ecological significance could be considered when choosing a target species.
    - Burbot, yellow perch
- Consideration of closely related taxonomic surrogates (same genus or family) for threatened or endangered species may be useful.
    - Bull Trout (T) – salmonids (RBT, WSCT)
- See spreadsheet matrix for criteria used in species selection

Data Considerations for BAF Approach

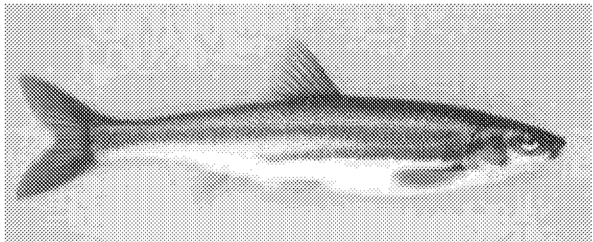


- Redside shiner – Cyprinidae
- Small home range/littoral - demersal
- Considerations for water data
  - Temporal – previous year? (consistent with mechanistic modeling assumptions)
  - **Spatial – station within close proximity of fish sample**

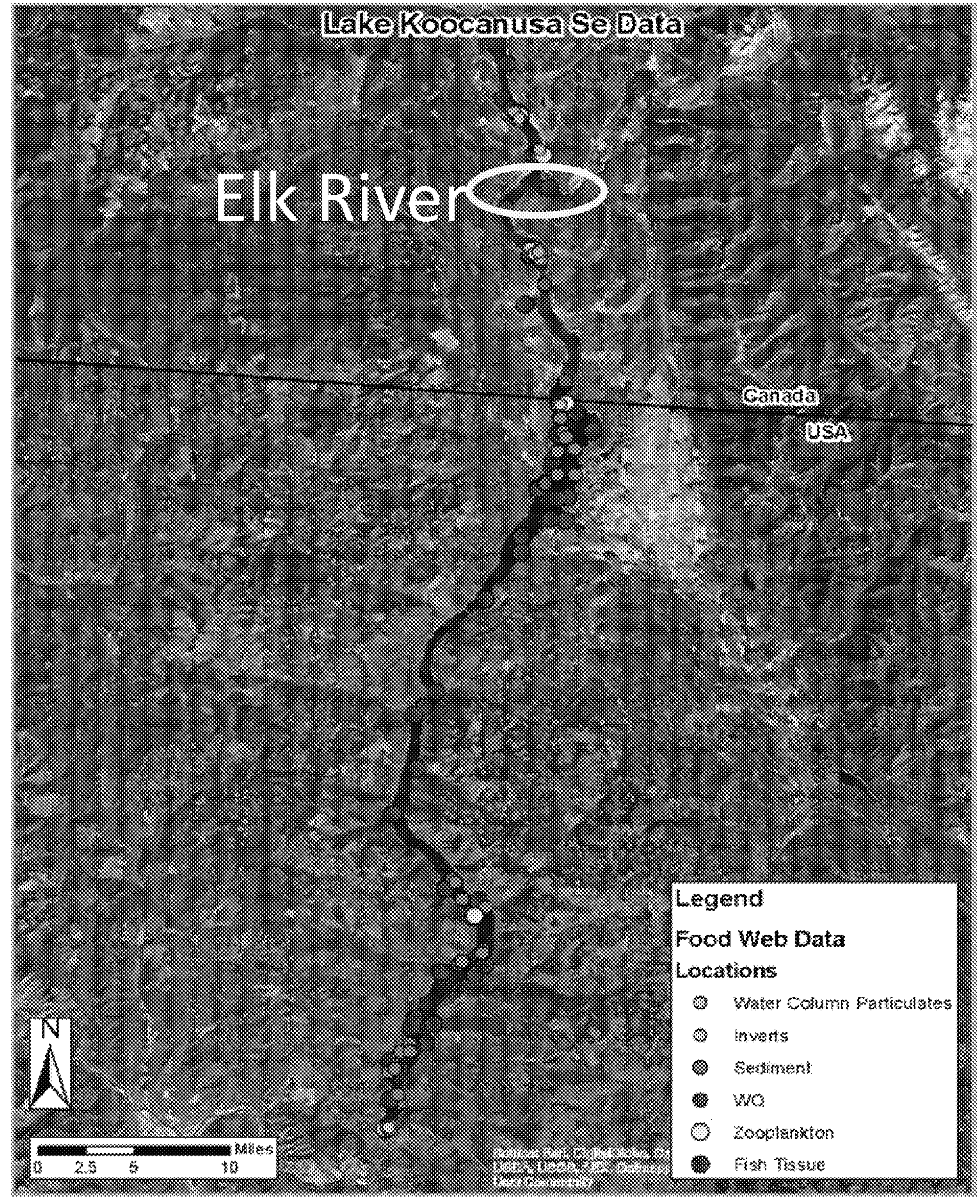


- Rainbow Trout - Salmonidae
- Large home range/pelagic
- Considerations for water data
  - Temporal – previous year? (consistent with mechanistic modeling assumptions)
  - **Spatial – lake-wide**

Example: 2015 Peamouth Chub near Elk River



- Cyprinidae (minnows)
- 9 to 12 inches in length; lifespan 6-8 yrs.
- littoral, demersal
- adult diet includes snails, aquatic and terrestrial insects
- Forage for larger predators (e.g., bull trout)



BAF Example Analysis – Water Data
Lake Koocanusa South of Elk River

Date	Site	Depth Zone	Se (ug/L)	Fraction	Comment	Location ID	Lat	Long
4/7/2015	E300230		1.77	Dissolved		LK2 - LAKE KOOCANUSA SOUTH OF ELK RIVER	49.14971	-115.258
4/7/2015	E300230		2.07	Dissolved		LK2 - LAKE KOOCANUSA SOUTH OF ELK RIVER	49.14971	-115.258
4/7/2015	E300230		2.86	Dissolved		LK2 - LAKE KOOCANUSA SOUTH OF ELK RIVER	49.14971	-115.258
4/14/2015	E300230		1.34	Dissolved		LK2 - LAKE KOOCANUSA SOUTH OF ELK RIVER	49.14971	-115.258
4/14/2015	E300230		3.48	Dissolved		LK2 - LAKE KOOCANUSA SOUTH OF ELK RIVER	49.14971	-115.258
4/14/2015	E300230		1.97	Dissolved		LK2 - LAKE KOOCANUSA SOUTH OF ELK RIVER	49.14971	-115.258

N	6	ug/L	10th	1.6	ug/L
Mean	2.2	ug/L	25th	1.8	ug/L
Geomean	2.1	ug/L	75th	2.7	ug/L
			90th	3.2	ug/L

BAF Example Analysis – Fish Tissue Data
Lake Koocanusa South of Elk River

Date	Site	(ug/g or mg/l	Anatomy	Wet.Dry	Species	Location ID	Lat	Long
4/1/2015	Elk River	10.9	Ovary	Dry	Peamouth	Koocanusa near Elk River	49.16726	-115.211
4/1/2015	Elk River	13.4	Ovary	Dry	Peamouth	Koocanusa near Elk River	49.16726	-115.211
4/1/2015	Elk River	10.1	Ovary	Dry	Peamouth	Koocanusa near Elk River	49.16726	-115.211
4/1/2015	Elk River	12.1	Ovary	Dry	Peamouth	Koocanusa near Elk River	49.16726	-115.211
4/1/2015	Elk River	14.2	Ovary	Dry	Peamouth	Koocanusa near Elk River	49.16726	-115.211
4/1/2015	Elk River	13.6	Ovary	Dry	Peamouth	Koocanusa near Elk River	49.16726	-115.211
4/1/2015	Elk River	17.3	Ovary	Dry	Peamouth	Koocanusa near Elk River	49.16726	-115.211
4/1/2015	Elk River	18.9	Ovary	Dry	Peamouth	Koocanusa near Elk River	49.16726	-115.211
4/1/2015	Elk River	14.6	Ovary	Dry	Peamouth	Koocanusa near Elk River	49.16726	-115.211
4/1/2015	Elk River	7.21	Ovary	Dry	Peamouth	Koocanusa near Elk River	49.16726	-115.211

N	10		10th	9.8	mg/kg
Mean	13.2	mg/kg	25th	11.2	mg/kg
Geomean	12.8	mg/kg	75th	14.5	mg/kg
			90th	17.5	mg/kg

BAF Calculation: Options 2 & 4 – Protection at Population Level for Species Present

Mean [Se] in Water (ug/L)		
EO	Water	BAF
7.21	2.2	3.3
10.1	2.2	4.6
10.9	2.2	5.0
12.1	2.2	5.5
13.4	2.2	6.1
13.6	2.2	6.2
14.2	2.2	6.5
14.6	2.2	6.6
17.3	2.2	7.9
18.9	2.2	8.6

N	10		10th	4.5	L/kg
Mean	6.0	L/kg	25th	5.1	L/kg
Geomean	5.8	L/kg	75th	6.6	L/kg
			90th	7.9	L/kg

For population level protection, we start with the average site water [Se] to calculate a distribution of BAFs using the peamouth egg-ovary data from the site

Options 2 & 4: Calculation of SSC (water ug/L)

Option 2: BC (11.0 mg/kg)

- $\text{SSC (ug/L)} = \dfrac{\text{BC egg-ovary (mg/kg)}}{\text{BAF (Kg/L)}}$
- $\text{SSC (ug/L)} = \dfrac{11.0\ \text{mg/kg}}{6.0\ \text{kg/L}}$

SSC = 1.83 ug/L

Use Mean BAF from Distribution of BAFs

Option 4: USEPA (15.1 mg/kg)

- $\text{SSC (ug/L)} = \dfrac{\text{BC egg-ovary (mg/kg)}}{\text{BAF (Kg/L)}}$
- $\text{SSC (ug/L)} = \dfrac{15.1\ \text{mg/kg}}{6.0\ \text{kg/L}}$

SSC = 2.52 ug/L

BAF Calculation: Options 2 & 4 – Protection at Population Level for Species Present

25th Centile [Se] in Water (ug/L)		
EO	Water	BAF
7.21	1.8	4.0
10.1	1.8	5.6
10.9	1.8	6.1
12.1	1.8	6.7
13.4	1.8	7.4
13.6	1.8	7.6
14.2	1.8	7.9
14.6	1.8	8.1
17.3	1.8	9.6
18.9	1.8	10.5

N	10		10th	5.5	L/kg
Mean	7.4	L/kg	25th	6.2	L/kg
Geomean	7.1	L/kg	75th	8.1	L/kg
			90th	9.7	L/kg

For individual level protection, we start with the 25^{th} centile site water [Se] to calculate a distribution of BAFs using the peamouth egg-ovary data from the site

Calculation of SSC (water ug/L)

Option 2: BC (11.0 mg/kg)

- $\text{SSC (ug/L)} = \dfrac{\text{BC egg-ovary (mg/kg)}}{\text{BAF (Kg/L)}}$
- $\text{SSC (ug/L)} = \dfrac{11.0 \text{ mg/kg}}{9.7 \text{ kg/L}}$

SSC = 1.13 ug/L

Option 4: USEPA (15.1 mg/kg)

- $\text{SSC (ug/L)} = \dfrac{\text{USEPA egg-ovary (mg/kg)}}{\text{BAF (Kg/L)}}$
- $\text{SSC (ug/L)} = \dfrac{15.1 \text{ mg/kg}}{9.7 \text{ kg/L}}$

SSC = 1.56 ug/L

Use 90th Centile BAF from Distribution of BAFs

Example: Summary of Potential SSCs

- Level of Protection Options:

1. Individual BC 11.0 mg/kg
2. Population BC 11.0 mg/kg
3. Individual USEPA 15.1 mg/kg
4. Population USEPA 15.1 mg/kg

- Corresponding SSCs [Se] ug/L

1. 1.13 ug/L
2. 1.83 ug/L
3. 1.56 ug/L
4. 2.52 ug/L

Example: Comparison of SSC to Site Data

Date	Site	Depth Zone	Se (ug/L)	Fraction	Comment	Location ID	Lat	Long
4/14/2015	E300230		1.34	Dissolved		LK2 - LAKE KOOCANUSA SOUTH OF ELK RIVER	49.14971	-115.258
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4/14/2015	E300230		3.48	Dissolved		LK2 - LAKE KOOCANUSA SOUTH OF ELK RIVER	49.14971	-115.258

- Average Site Water [Se] for April 2015 = 2.2 ug/L.
- Site would attain only using the species population protection level using the USEPA EO criterion at 15.1 mg/kg = 2.52

Key Points

- This is just an example! BAF modeling assumptions will be consistent with modeling assumptions developed for the mechanistic modeling runs based on the levels of protection decided on by decisionmakers.
- The BAF is secondary to the mechanistic model (due to greater uncertainty), and will be used to ground truth those results, therefore the results for both the mechanistic model and the BAF model should be similar (to the extent the data allows).
- Because the assumptions for BAF modeling runs will be used for a ground truth comparison to the mechanistic model, SeTSC decisions for each of the modeling parameters (target species, EF, TTF, CF) will need to be documented prior to BAF model runs.
- Uncertainty analysis, whether qualitative or quantitative will need to be transparently documented for the regulatory record.